Observation impact on the convection-permitting scale using an observation-based verification metric

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In close collaboration with Deutscher Wetterdienst. Special thanks to Roland Potthast, Hendrik Reich as well as all others from DWD who contributed to this work.

I. Motivation – Observation impact in ensemble systems

Why assessment of observation impact?

- **Detect issues** with certain observations and their assimilation
- Optimizing the **observing, data assimilation** and **forecasting** system
- Enhance the **cost-benefit ratio**

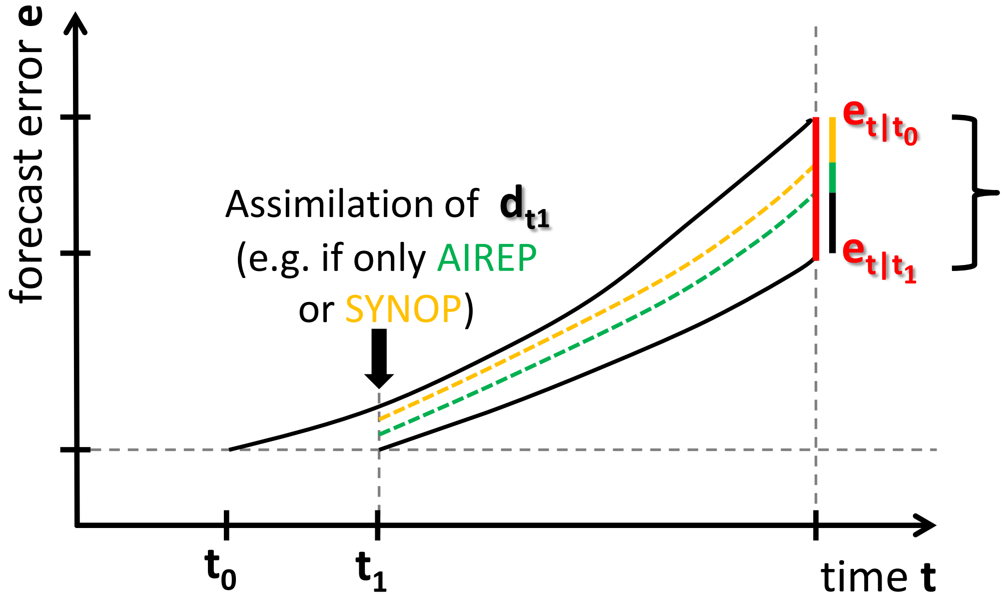
Why approximation of the observation impact?

- COSMO-KENDA of DWD is an **ensemble system** / no adjoint model available
- Very low **computational cost** as ensemble is computed anyway
  (data denial is too expensive)

Goals:

- Estimate the **impact of observations in** the pre-operational **regional LETKF DA system** of Deutscher Wetterdienst (DWD)
- **Verification with** independent **observations**
  (Instead of model analysis)

II. Method – Theoretical background



Observation Impact ***J(d)***

…measured as forecast error difference

All observations **d**

…used in the analysis
(AIREP, PROF, SYNOP, TEMP)

$J = \frac{1}{2}(\vert\mathbf{e}_{t\vert t_1}\vert^2 - \vert\mathbf{e}_{t\vert t_0}\vert^2)$	Forecast error difference
$\mathbf{e}_{t\vert t_0} = \overline{\mathbf{x}}_{t\vert t_0} - \mathbf{x}^V{}_t$	Error of forecast initialized at t_0
$\mathbf{e}_{t\vert t_1} = \overline{\mathbf{x}}_{t\vert t_1} - \mathbf{x}^V{}_t$	Error of forecast initialized at t_1
$\overline{\mathbf{x}}_{t\vert t_0}, \overline{\mathbf{x}}_{t\vert t_1}$	Forecast means
$\mathbf{x}^V{}_t$	Verification

Goal: Contribution of different observations to the reduction of forecast error

By definition:

Negative **J -** beneficial impact

Positive **J -** detrimental impact

II. Method – Calculation of the observation Impact (J)

J : Observation Impact

$\boldsymbol{Y}_f^d$: Forecast ensemble in obs . space

$\boldsymbol{Y}_a^d$: Analysis ensemble

$\boldsymbol{R}$: Obs. error cov. matrix

$$J(\boldsymbol{d}') \approx \frac{2}{N_e - 1} \boldsymbol{e}_f^d \cdot \boldsymbol{Y}_f^d \left(\boldsymbol{Y}_a^d\right)^T \boldsymbol{R}^{-1} \boldsymbol{d}'$$

N_e: Number of ensemble member

$\boldsymbol{d}'$: Innovation vector of subset of observation

$$\boldsymbol{d} = \boldsymbol{y_o} - \boldsymbol{y_b}$$

$\boldsymbol{e}_f^d$: Forecast error

$$\boldsymbol{e}_f^d = \overline{\boldsymbol{H}_{veri}\left(\boldsymbol{x}_f^d\right)} - \boldsymbol{y}_{veri}$$

$\boldsymbol{y}_{veri}$: Observation used for verification

$\boldsymbol{H}_{veri}$: observation operator into verification space

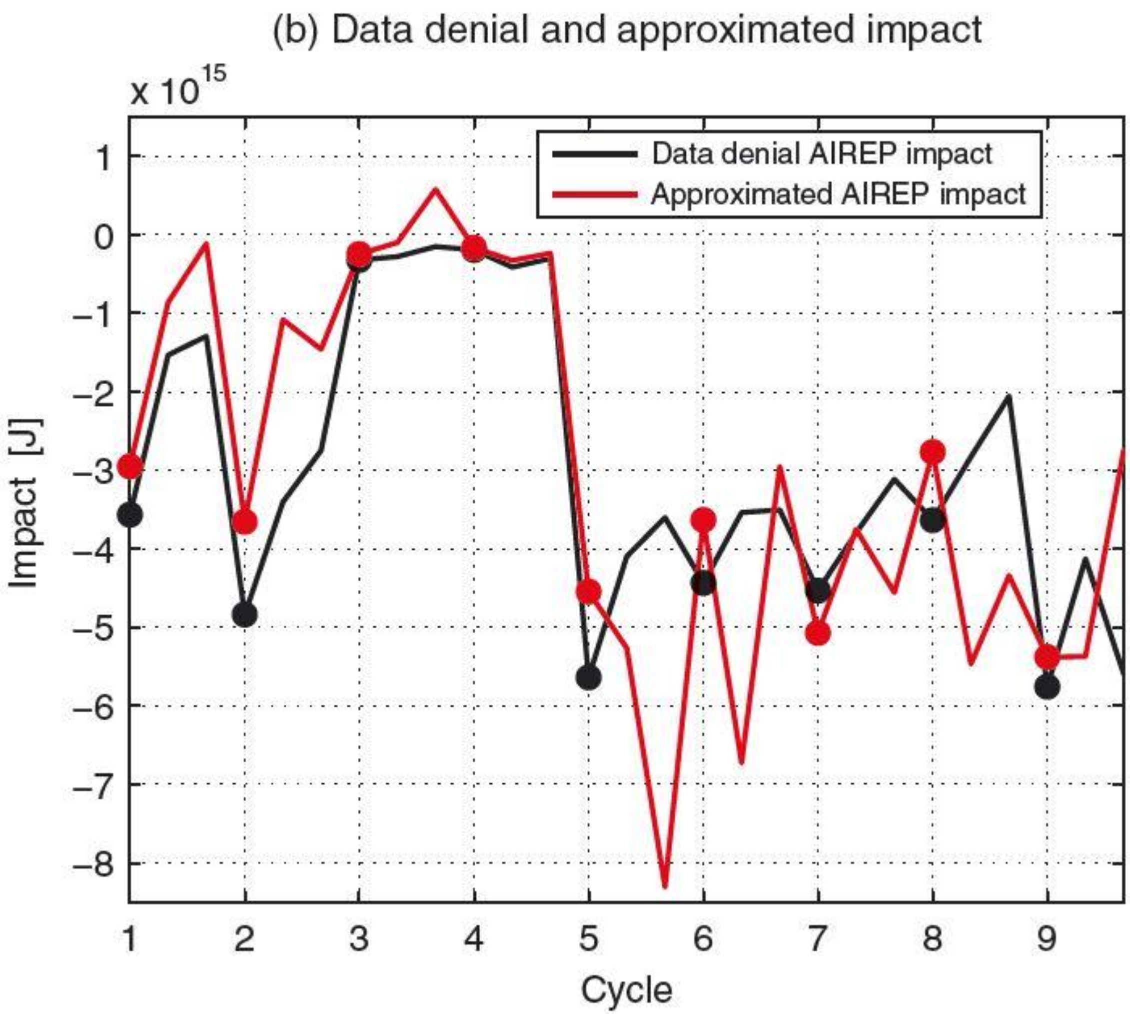
Super-script ”d”: set of observations used in analysis

Sub-script “f”: forecast

(Following Kalnay et al 2012)

(Reformulated by Sommer & Weissmann 2016)

II. Method - Comparison to data denial



Impact time series of AIREP observations from the **data denial experiment *(black)*** and **approximation *(red)***.
Values are displayed for initialization time *(solid circles)* and forecasts up to 6 h *(lines)*.

COSMO-DE / KENDA LETKF
32 member
7 - 9 August 2009

(Sommer & Weissmann 2014)

II. Method – Verification with observations

Sensitivity to the verification metric: Impact depends on the set of verifying observations

-> Use **independent as well as full set of observations** for the verification:

Remote Sensing observations (Radar precipitation & GNSS IWV humidity)

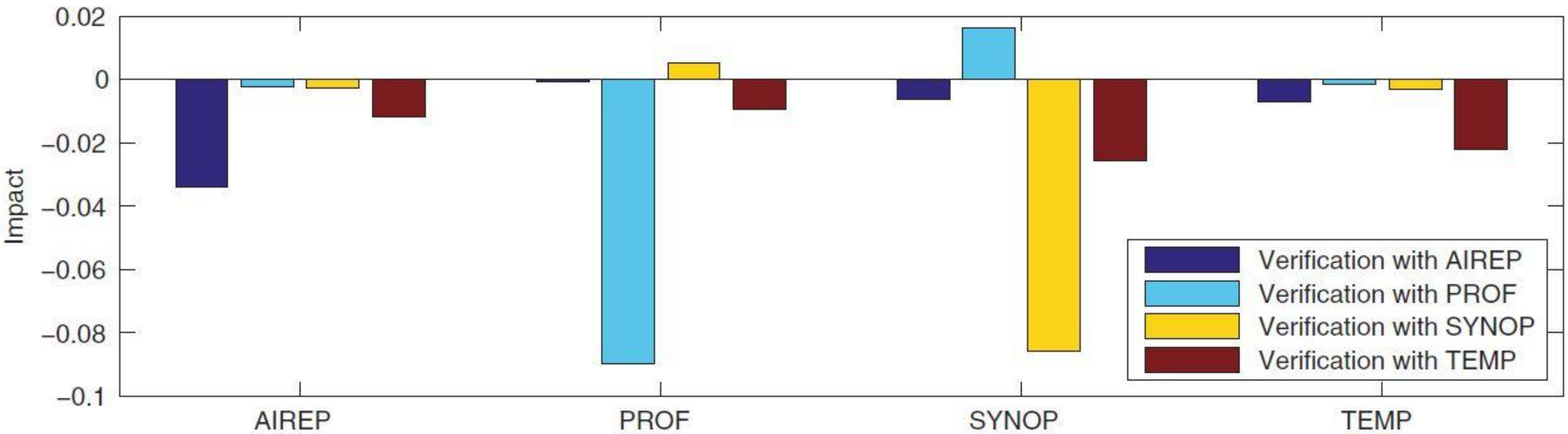


Fig. 4. Approximated observation impact summed over the experimental period using different observation types for verification.

(Sommer & Weissmann 2016)

III. Experimental setup

Period:

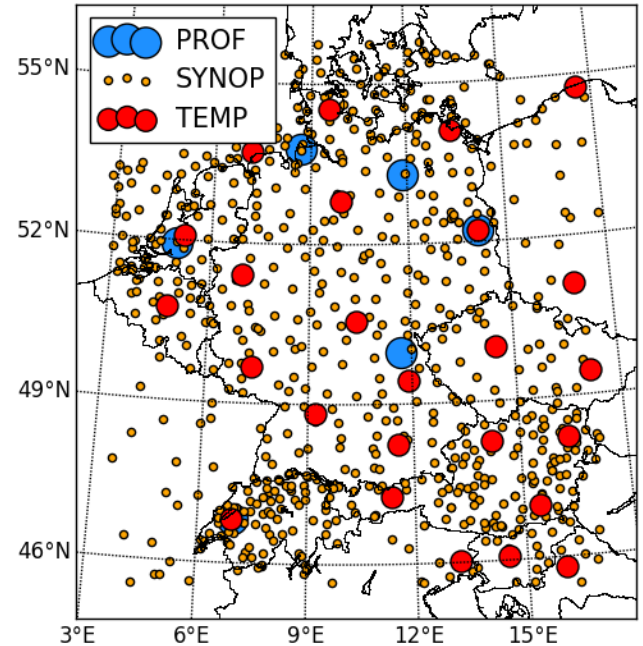
- 14 days (112 cycles): 17.-30. May 2014
- Summer period with convective precipitation

Model:

- Regional COSMO-KENDA (LETKF) ensemble system of DWD *(40 member)*
- Convection permitting model *(2.8km grid spacing)*

Setup:

- Initial and boundary conditions: ICON
- 1-day spin up
- 3h cycling /**verification window 1-3 h after analysis**
- Operational setup of DWD except:
  - No adaptive localization (lh: 100km / lv: ln(p)=0.3)
  - No adaptive inflation



Stations of different observation types in the COSMO-DE domain

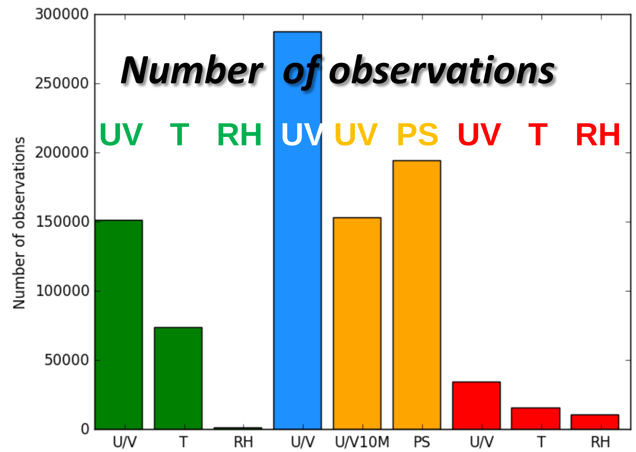
HErZ Munich: tobias.m.necker@lmu.de

IV. Results - Verification with independent observations

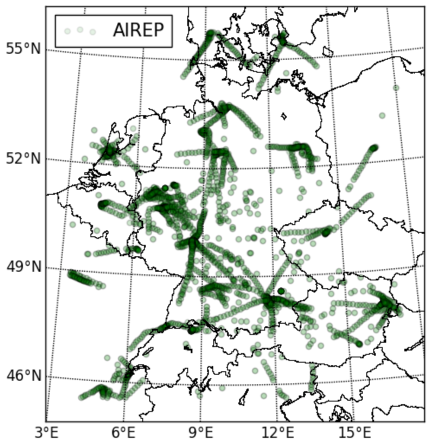
Verification with observations:

>>> Conventional <<<

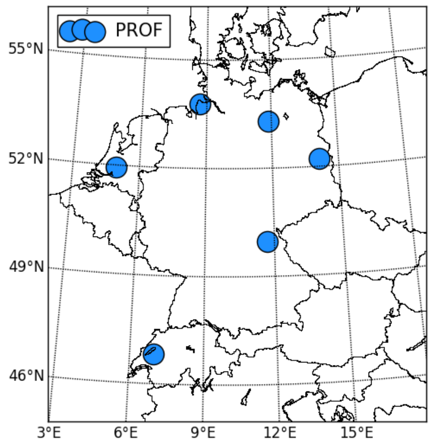
Maps for 17.05.2014
Histogram for 17. - 30.05.2014



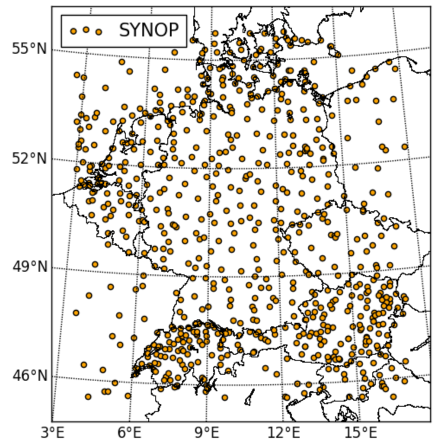
AIREP
(U/V, T)



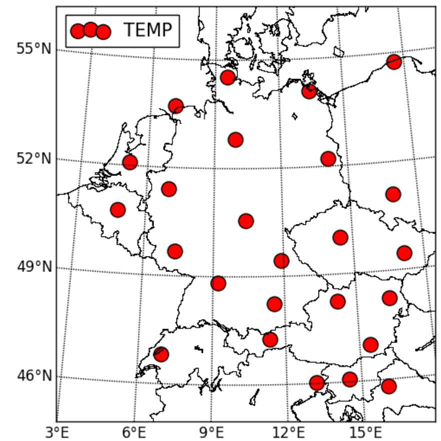
PROF
(U/V)



SYNOP
(U/V10M, PS)



TEMP
(U/V, T, RH)

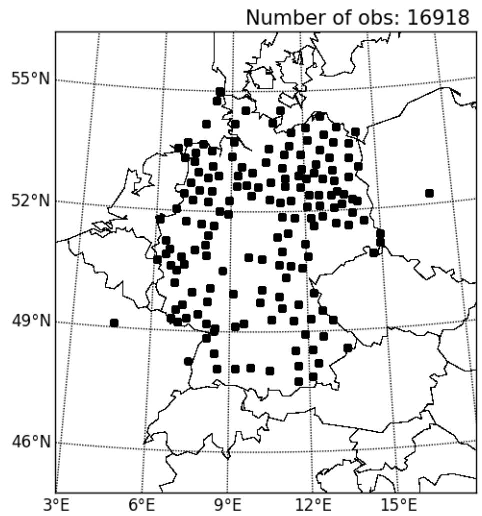


IV. Results - Verification with independent observations

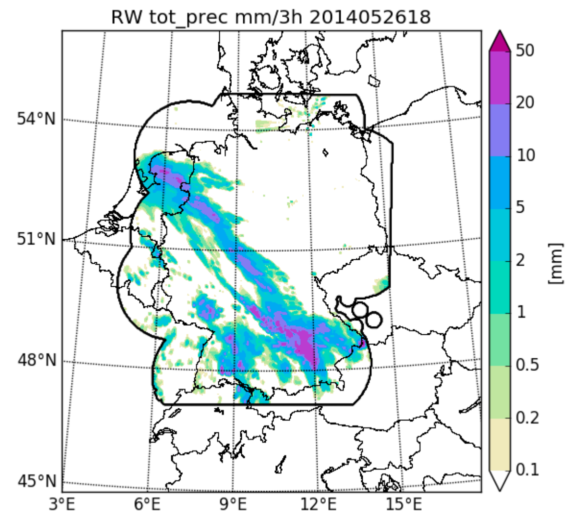
Verification with observations: **>>> *Remote Sensing* <<<**

- Humidity (GNSS IWV):
  + increased number of RH verifying observations
  + good temporal & spatial coverage
- Precipitation (Radar product):
  + primary forecast quantity
  + user relevant
  + spatial coverage

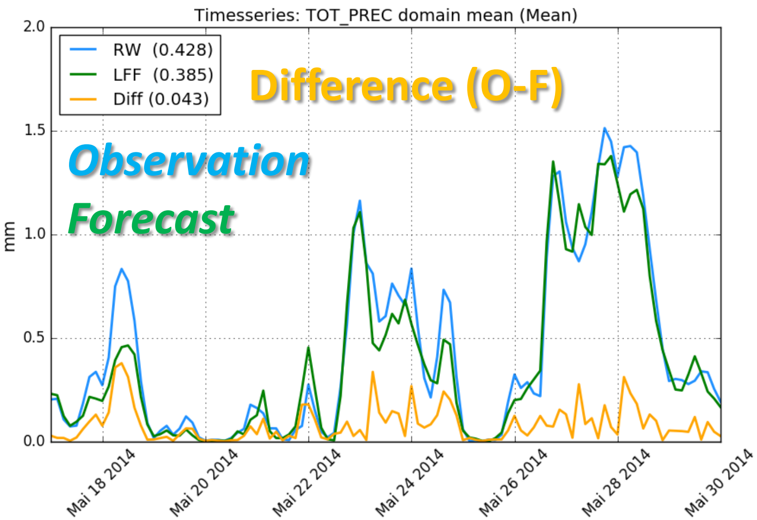
***Humidity** GPS Stations*



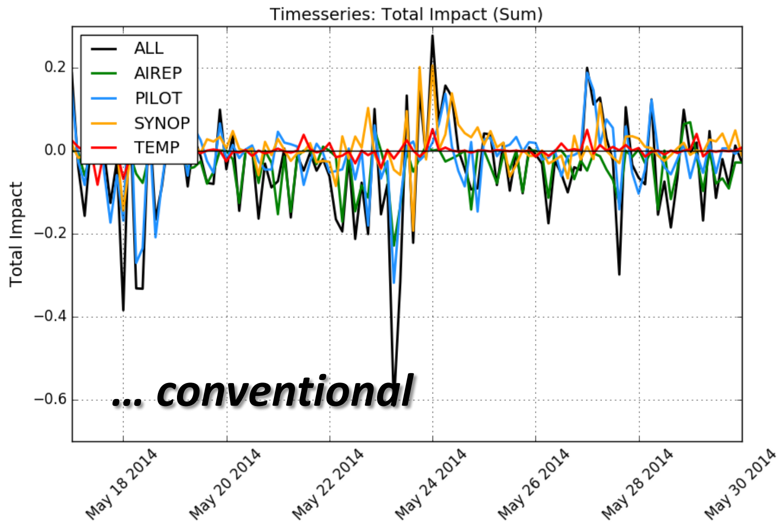
***Precipitation** [mm/3h]*



Domain mean precipitation



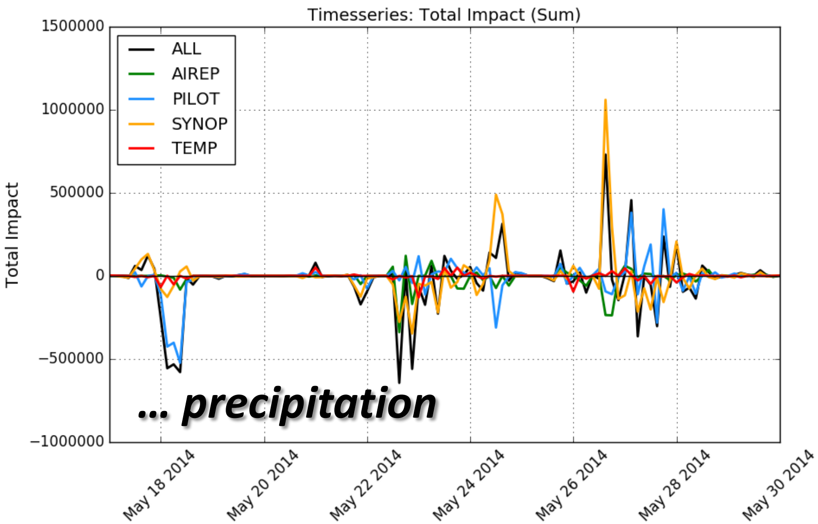
IV. Results – Time series of the total impact

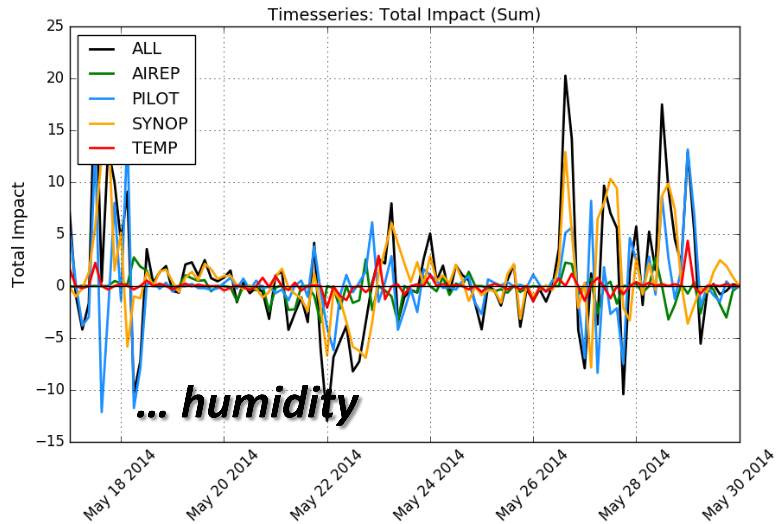


- Impact varies strongly with time
- Remote Sensing verification shows larger impacts for rainy days
- Impact Ratio - (Pos. : Neg.) - (48% : 52%)

Impact of AIREP PROF SYNOP TEMP SUM

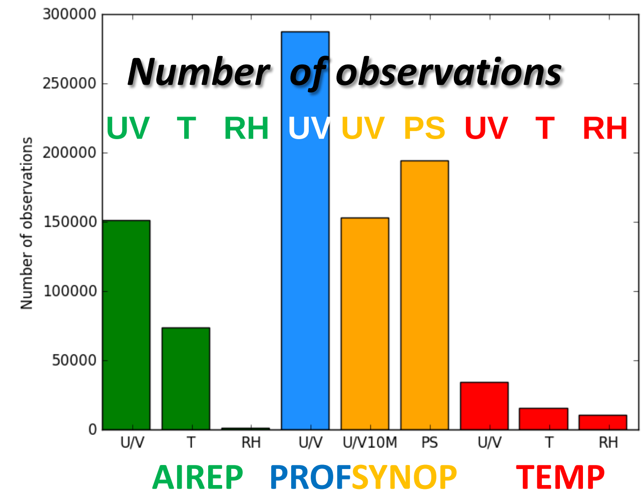
Verification with …





IV. Results – Total impact

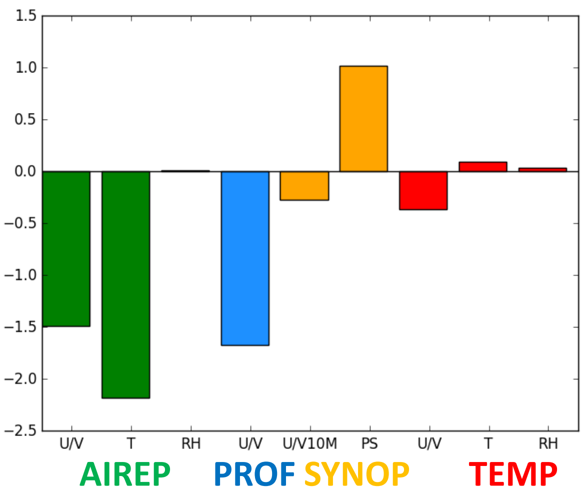
- Beneficial impact for most observations except AIREP RH (small sample!) and SYNOP PS (bias?)
- Verification with precipitation shows reasonable results
- Verification with humidity shows ambiguous results



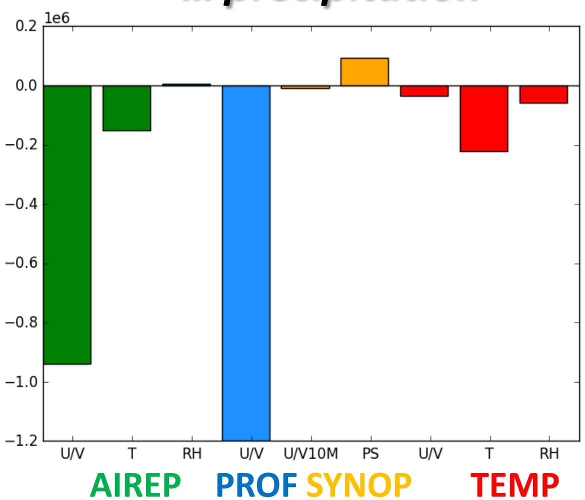
Verification with …

Total Impact

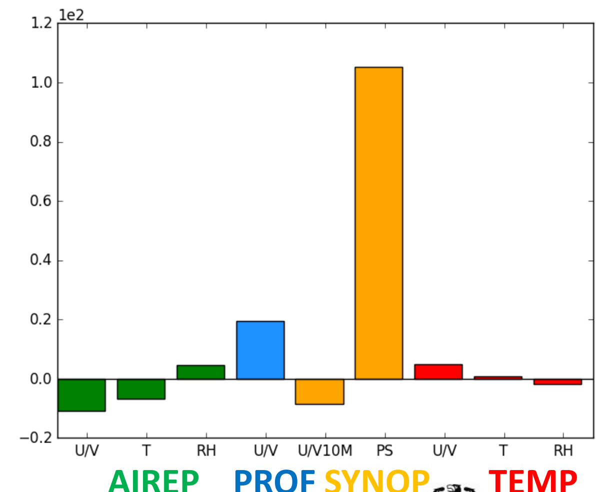
… conventional



… precipitation



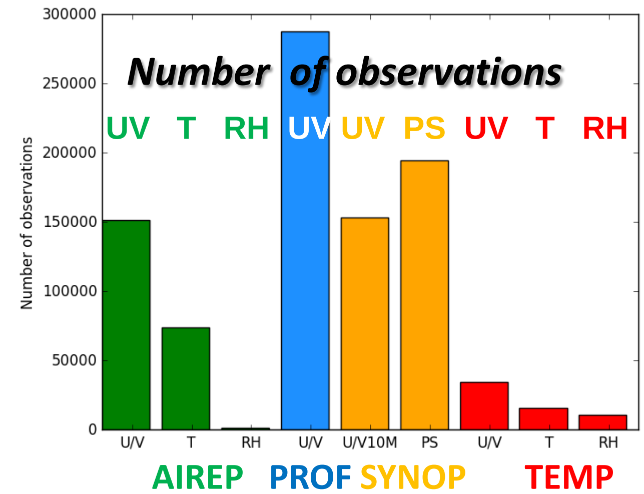
… humidity



IV. Results – Mean impact per observation

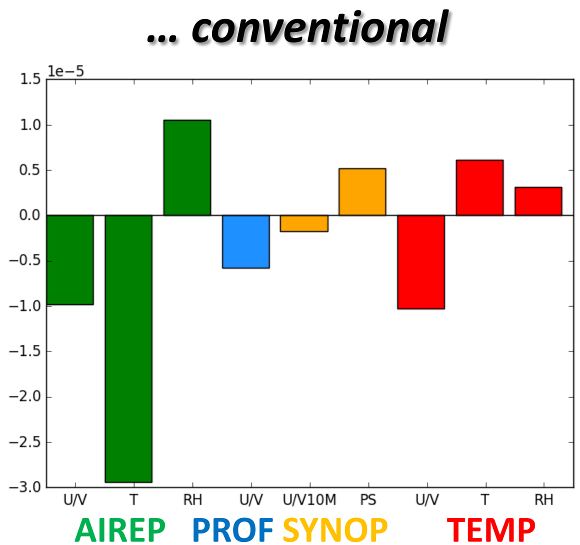
- Verification with conventional and precipitation observations shows similar results except for TEMP
  (TEMPs usually good verification but due to setup only few tropospheric soundings for verification)

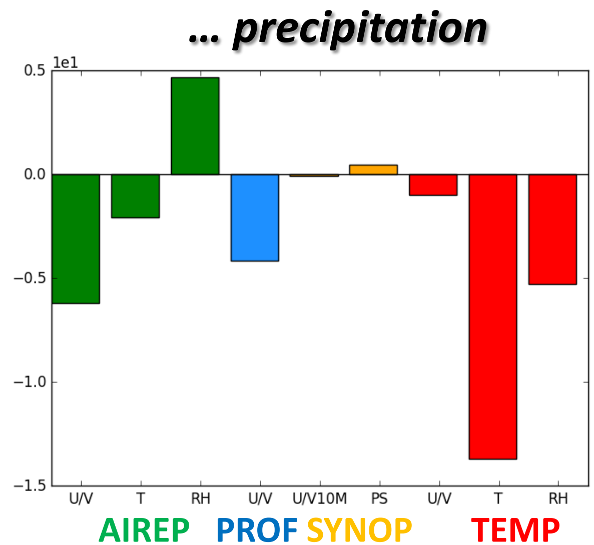
- Verification with humidity shows largest impacts for RH observations

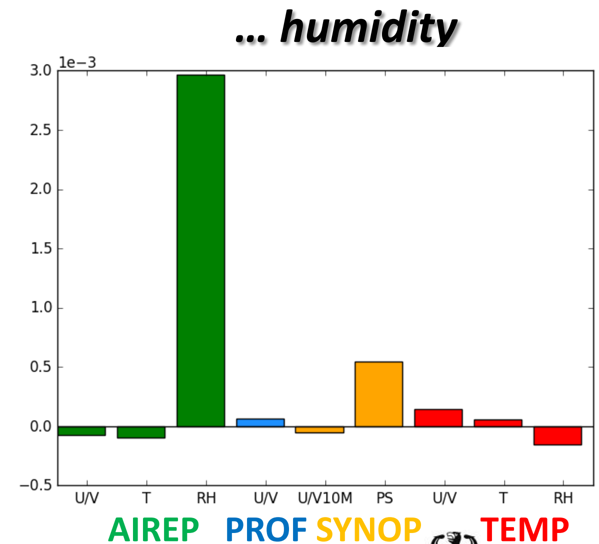


Verification with …

Average Impact







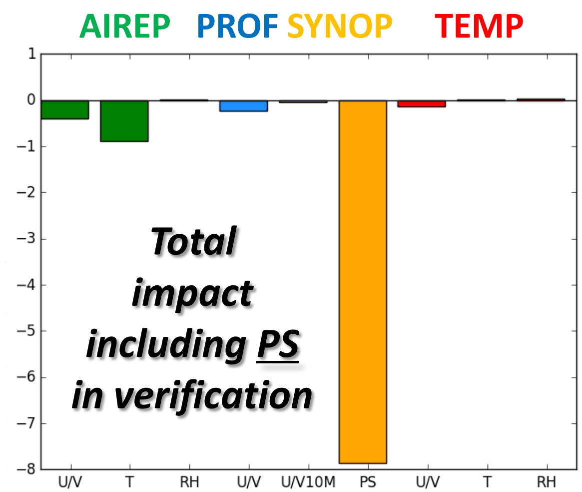
V. Characteristics of the method - Biases

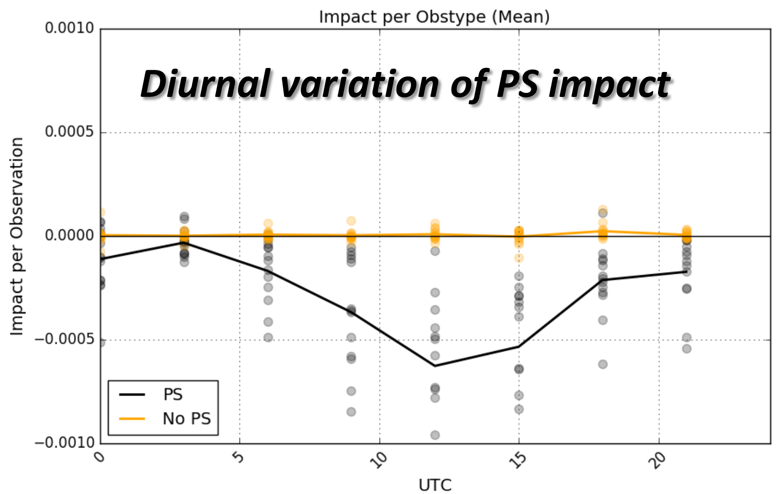
Verification with conventional + surface pressure (PS)

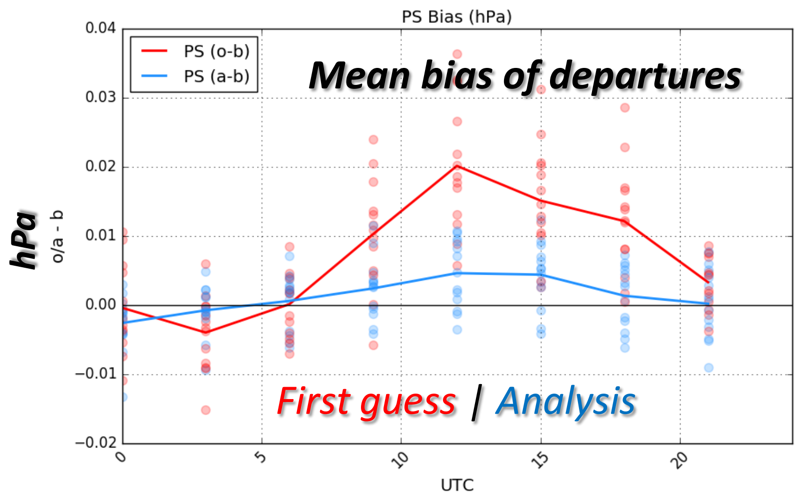
- Large beneficial impact for surface pressure if verified with later pressure observations

- Impact seems to be dominated by samll bias of 2 Pa (≈ 10% of departure)

→ Further investigation/sensitivity studies required





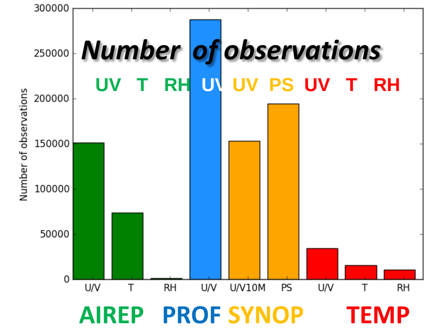


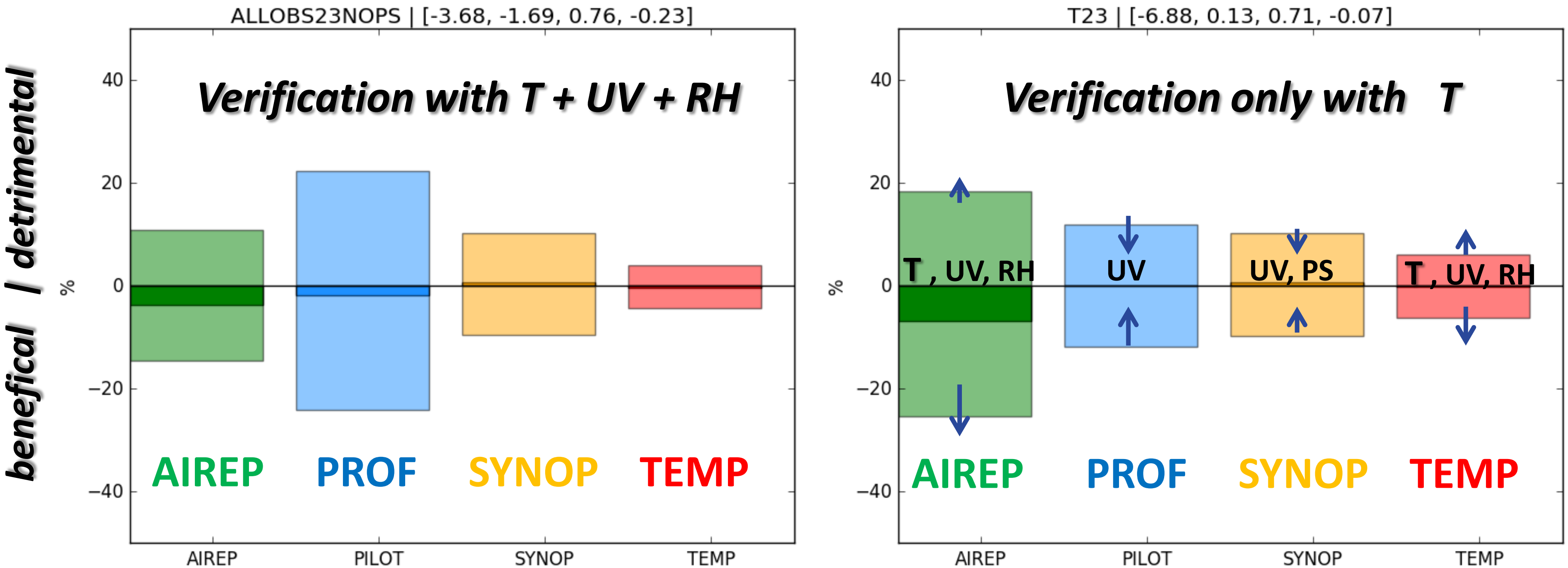
V. Characteristics of the method – Sensitivity

Sensitivity to the verification metric

Relative contribution to the total impact [%]

-> Full set of observations needed for reliable verification





V. Characteristics of the method – Localization

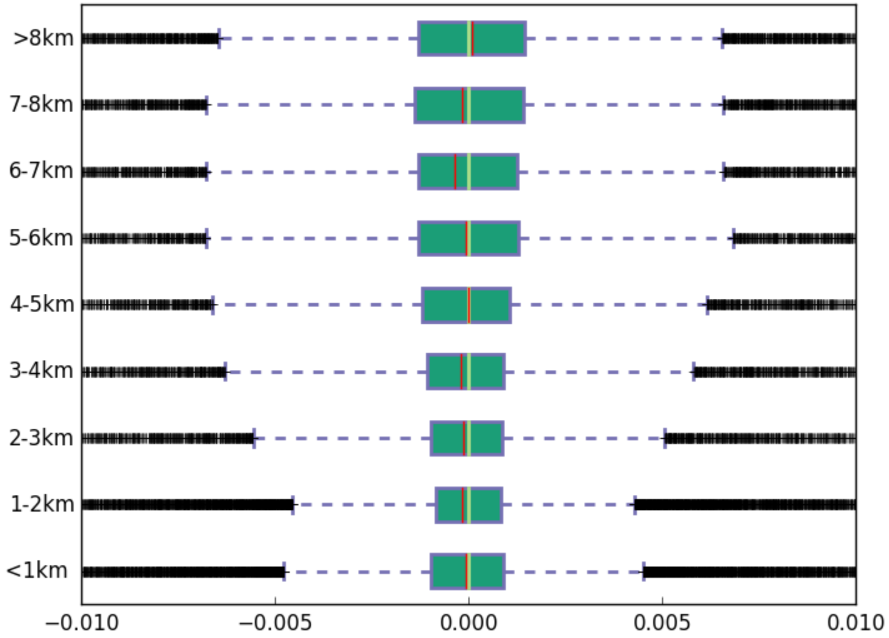
-> Conventional: *verification = assimilation localization*

-> Remote Sensing: *Precipitation without vertical localization*

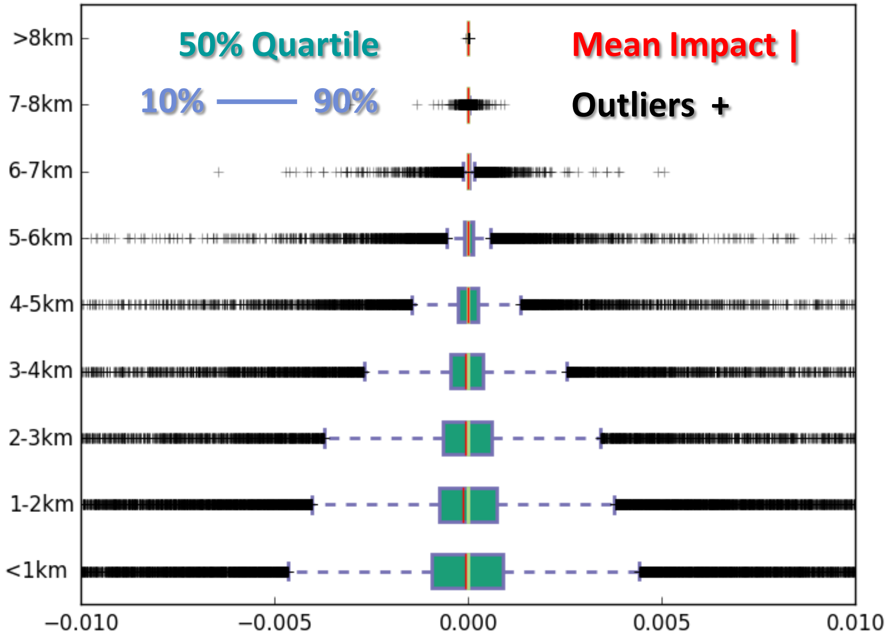
Humidity vertical localization reasonable

Localization of non-local GNSS IWV observations in the verification

Height distribution of the AIREP impact ***(Box - Whisker - Plot)***

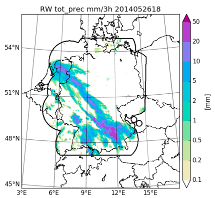


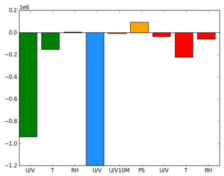
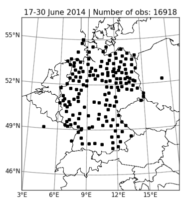
No vertical localization

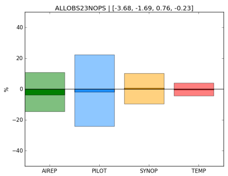


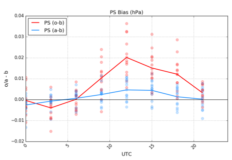
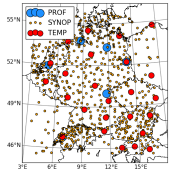
With vertical localization

VII. Summary





- Method is **adapted to verify with independent remote sensing** observations: **Precipitation** (Radar Product) & **Humidity** (GPS IWV).
- **Verification with conventional & precipitation** observations for a 14 day test period in Mai 2014 show beneficial impacts for most observations (except for small sample of RH & biased PS).
- Applying the **GNSS IWV** can fill the lack of too few RH observations in the verification of with conventional observations.
- Impact approximation is **sensible to the verification metric.** Set of observations for verification should be as complete as possible.
- A **bias** (as seen for surface pressure) seems to be an issue.
- Various studies work on **assimilation of remote sensing /satellite data** which makes a **cheap evaluation tool** more crucial in future.
  -> Talk by Leonhard Scheck

Collaborations & Literature

Thanks to all people from **Deutscher Wetterdienst** who contributed to this work.

Thanks to all people form **Hans-Ertel-Centre for Weather Research** (HErZ) and **Meteorological Institute Munich** (MIM) who contributed to this work.

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Sommer, M. and M. Weissmann, 2016: Ensemble-based approximation of observation impact using an observation-based verification metric. *Tellus A, accepted.* DOI: 10.3402/tellusa.v68.27885

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Kalnay, E. et al. 2012: A simpler formulation of forecast sensitivity to observations: Application to an ensemble transfrom Kalman filter. Physica D, 230: 112-126. DOI: 10.3402/tellusa.v64i0.18462